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Technical Note

169

PROFILES OF ELECTRON DENSITY OVER THE MAGNETIC EQUATOR OBTAINED USING THE INCOHERENT SCATTER TECHNIQUE

K. L. BOWLES et al.



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Profiles of Electron Density Over the Magnetic Equator
Obtained Using the Incoherent Scatter Technique

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and

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A joint venture of the National Bureau of Standards, Boulder, Colorado,
and the Instituto Geofísico del Perú, Lima, Perú

The technique of electron density measurement by incoherent scatter, using a high powered radar, has now been thoroughly explored in the literature. A representative bibliography on the subject, as well as a summary of experimental aspects, current early in 1962, has been given by Bowles, Ochs, and Green [1962]. The object of this note is to present a number of profiles obtained using incoherent scatter near Lima, Perú.

It appears that the theory of the "incoherent scatter" phenomenon, as applied to the ionosphere and exosphere, is now well established. The scattering cross section per free electron, σ , is related to the classical Thomson cross section σ_{th} by the approximate formula

$$\sigma = \sigma_{th} \left[\frac{1}{1 + T_e/T_i} \right] \quad (1)$$

as long as

$$\lambda < < 4\pi\lambda_D \quad (2)$$

where T_e and T_i are the electron and ion kinetic temperatures, respectively, λ is the radio wavelength and λ_D is the Debye shielding distance. For all of the experiments to be discussed in this note, the inequality (2) is correct.

At first there appeared to be some question as to the validity of (1), raised by some of the experimental results. The paper of Bowles et al. [1962] showed that the scattering cross section measured experimentally is within about 20 percent experimental error of agreeing with the theory, at least under conditions of thermal equilibrium. Recently Renau [1962] has questioned the earlier theories, all of which led to (1), and suggests that $\sigma \rightarrow \sigma_{th}$ as T_e/T_i increases. Unfortunately Renau's theory leads to the inconsistent result that the electron and ion fluctuations behave quite differently as T_e/T_i changes, a result which is known to be impossible from the theorem of charge neutrality. Quite recently Evans, in work which will be published shortly [J. V. Evans, private communication, 1962], has obtained accurate spectra of incoherent scattered echoes observed in Massachusetts. These spectra agree precisely with the earlier theoretical spectra, which correspond with (1), and apparently do not agree with Renau's spectra. Thus we assume, for the present purpose, that (1) is correct.

Now the ratio T_e/T_i can be measured from the incoherent scatter echoes by observing the spectrum of the scattered energy. Unfortunately we were not prepared to make such measurements when the profiles given herein were obtained. We estimated [Bowles et al., 1962] that at Lima, and at the F2 layer maximum, T_e/T_i approximates unity during the majority of the daylight hours, and approximates 2 just at sunrise in the F region. We had very little data for the nighttime hours. On the other hand, [Evans, private communication, 1962] finds that in Massachusetts T_e/T_i approximates unity during the hours of darkness and rises to about 1.6 at midday at heights from 300 to 600 km. Other reports also seem to indicate that thermal equilibrium is by no means necessary and that values of T_e/T_i approximating 2 or more are quite common.

The profiles given in this note are therefore subject to whatever errors might be introduced by variations in T_e/T_i with height at any given time. Obviously if T_e/T_i does not vary with height, σ is the same at all heights and the profiles are plotted correctly.

Only one point on the profiles is directly related to the correct electron density. This is the point of maximum electron density, the value of which is obtained from the ordinary-trace penetration frequency of a conventional swept-frequency ionogram. All other points are relative measurements normalized to the maximum value. The error flags shown on the profiles give only the relative accuracy for scaling the incoherent scatter echo power which is proportional to the electron density at each height. No errors due to variations of T_e/T_i are shown.

It may be seen that most of the profiles were obtained in three distinct sections. Error flags appearing in the vicinity of 700 km height pertain to the section of the profile which also includes the F layer maximum. The incoherent scatter technique uses direct measurements of echo power. The sensitivity of the radar decreases with height h as $1/h^2$. Therefore the measurement involves observations over a dynamic range of more than 50 decibels of received power. This requires operating the radar at three different sensitivities in succession in order to obtain the entire profile. At the higher sensitivities measurements cannot be made at the F layer maximum due to saturation of the radar receiver. Therefore the complete profile is a composite obtained by fitting sections of profile obtained at three different sensitivities. The accuracy of the higher sections obviously depends upon the accuracy of curve fitting. Readers may judge for themselves whether the fitting has been done properly, since data points pertaining to each section of the profile have been plotted using distinct symbols. In some of the profiles, all of the available data points have been plotted individually. In others only a few have been plotted as a means of identifying the three sections of profile.

At times coherent irregularities are present at certain heights giving rise to radar echoes stronger than the background of incoherent scatter. The most obvious of these are associated with the appearance of spread-F echoes on the conventional swept frequency ionograms. When the spread-F is intense it has proven impossible to obtain reliable electron density profiles. At times of weak spread F we have excluded the range of heights corresponding to the spread-F echoes from the electron density analysis. Now it may logically be asked whether our observations are not always contaminated to some extent with scattered power due to coherent irregularities. Having been unable as yet to make adequate spectrum observations we have not yet been able to exclude the coherent echoes from the electron density observations with absolute certainty. However several factors lead us to believe that the coherent irregularities are normally of trivial importance. First, the coherent irregularities in the E region and above are always observed to be quite aspect sensitive and aligned with the lines of force of the earth's magnetic field. Therefore the echoes due to these irregularities must maximize in an angular region within about 1 degree of perpendicular to the lines of force, according to our spread-F observations. Except when spread F is also observed with the ionosonde, there is no evidence of significant echo power from coherent irregularities even when the radar antenna is directed perpendicular to the magnetic field line in the F region. All of the profiles of electron density reported herein were obtained with the antenna directed 3 degrees away from perpendicularity. Under this arrangement the coherent echo power should be reduced perhaps three to four orders of magnitude relative to the perpendicular direction. Therefore we feel justified in ignoring the coherent irregularities for analysis of most of the profiles presented herein. Exceptions are noted directly on the graphs.

At heights below about 200 km there is some evidence that the indicated electron densities are up to a factor of 2 too high. This is suggested by comparisons made using the so-called true height method of analysis of conventional ionograms. Below 200 km the mean free path of the gas becomes short enough that coherent irregularities due to turbulence and other hydrodynamic sources may become of some concern. Also the role of collisions in the incoherent scatter process is not yet well understood. We are making efforts to understand the scatter from this height region better. For the present it must be assumed that the profiles given in this note are reliable only above 200 km, and that the electron densities indicated below that height are overestimated.

Most of the details of our technique in making incoherent scatter profile measurements have been given in the paper by Bowles et al. [1962]. In the profiles given herein, the transmitter peak power P_t and antenna cross section A were as follows:

January 1962	$P_t = 10^6$ watts	$A = 2.1 \times 10^4 \text{ m}^2$
February 1962	$P_t = 2 \times 10^6$ watts	$A = 4.2 \times 10^4$
April 1962 et seq.	$P_t = 4.5 \times 10^6$	$A = 8.4 \times 10^4 \text{ m}^2$.

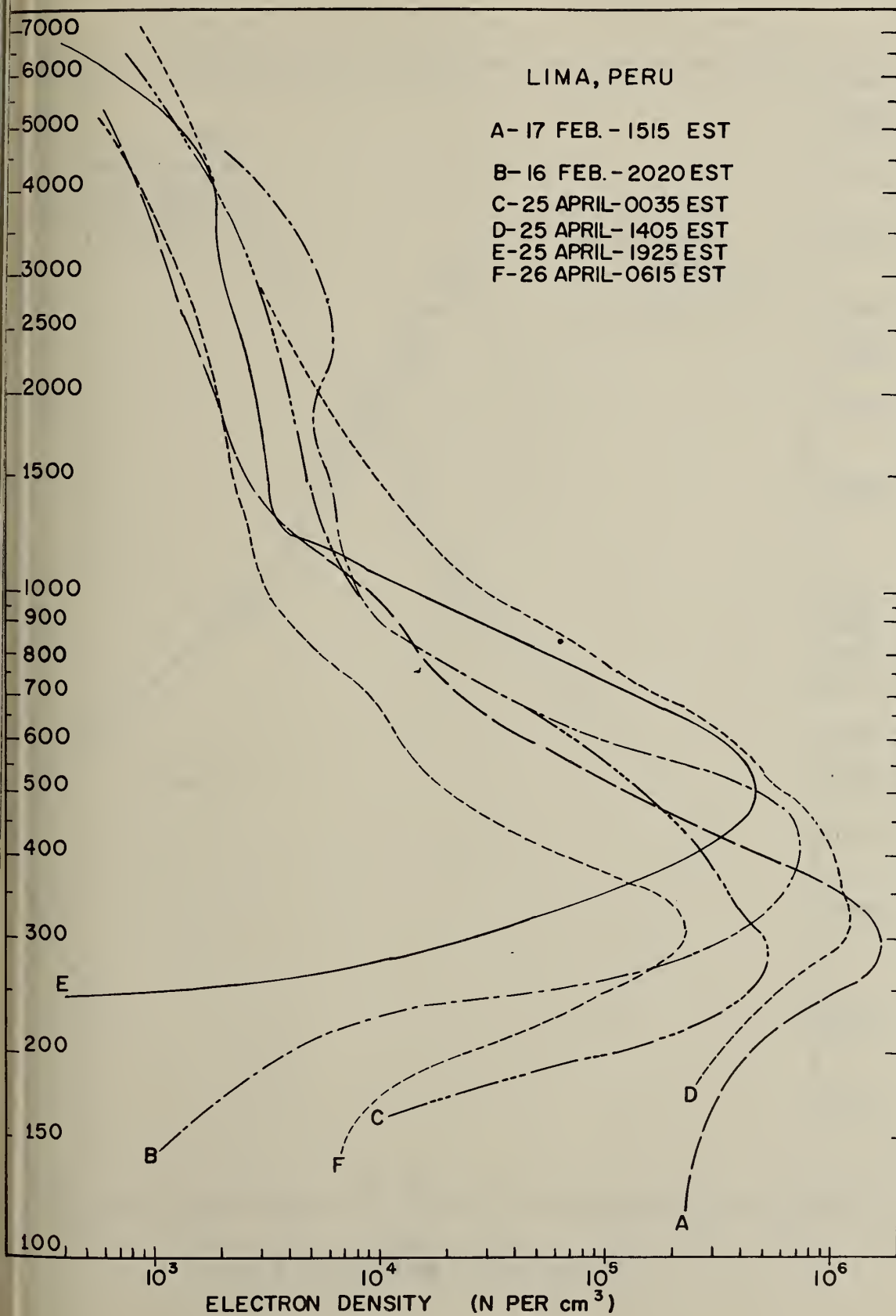
In February and following, the top section of the profile was extended through the use of longer pulses (up to 3 milliseconds) and improved in integration of the receiver output.

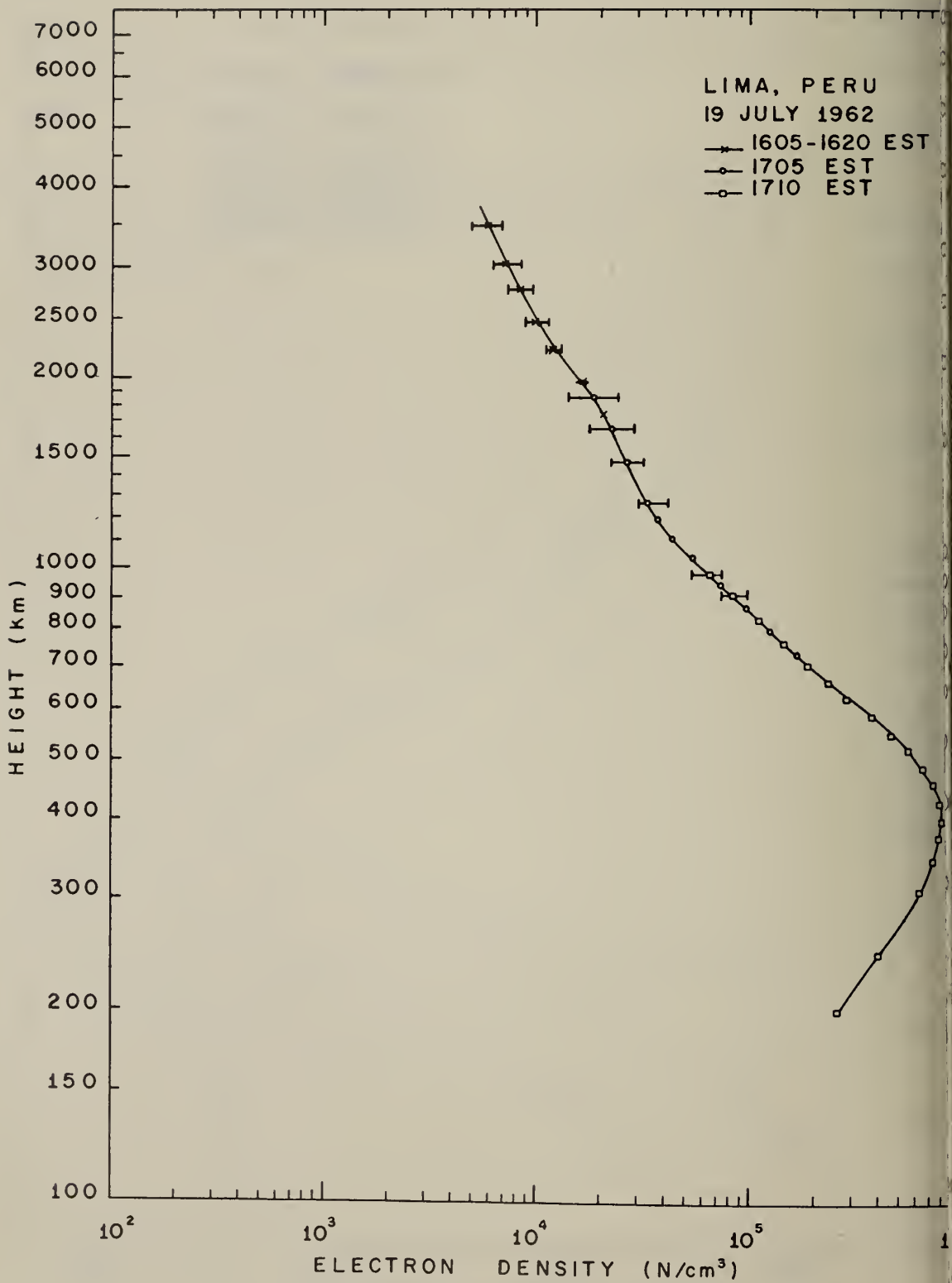
Our experimental program includes the measurement of the incoherent scatter spectrum in order to determine T_e/T_i . Equipment to permit this is now essentially complete. Every effort will be made to produce profiles in greater quantities and for longer periods of continuous operation.

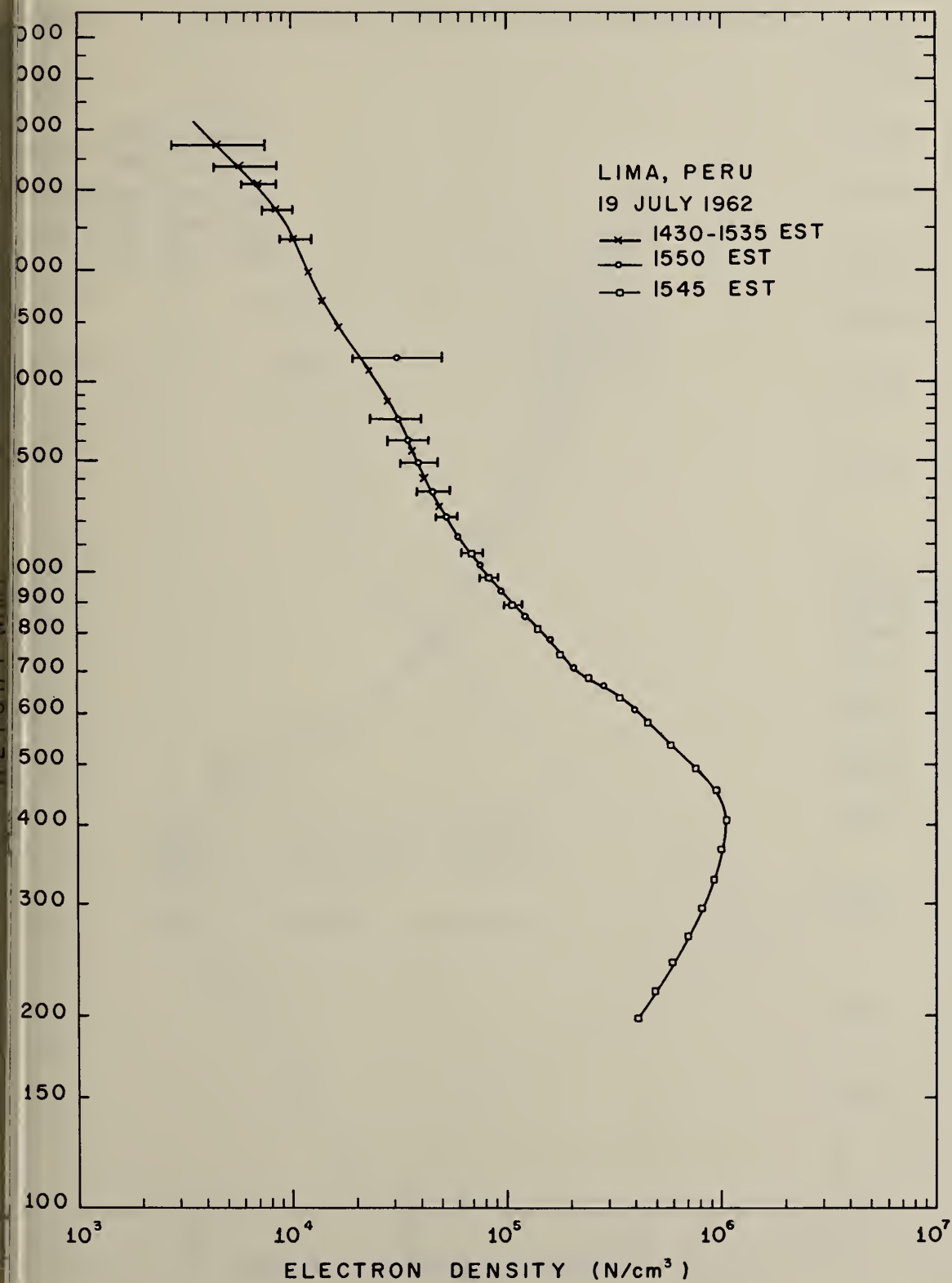
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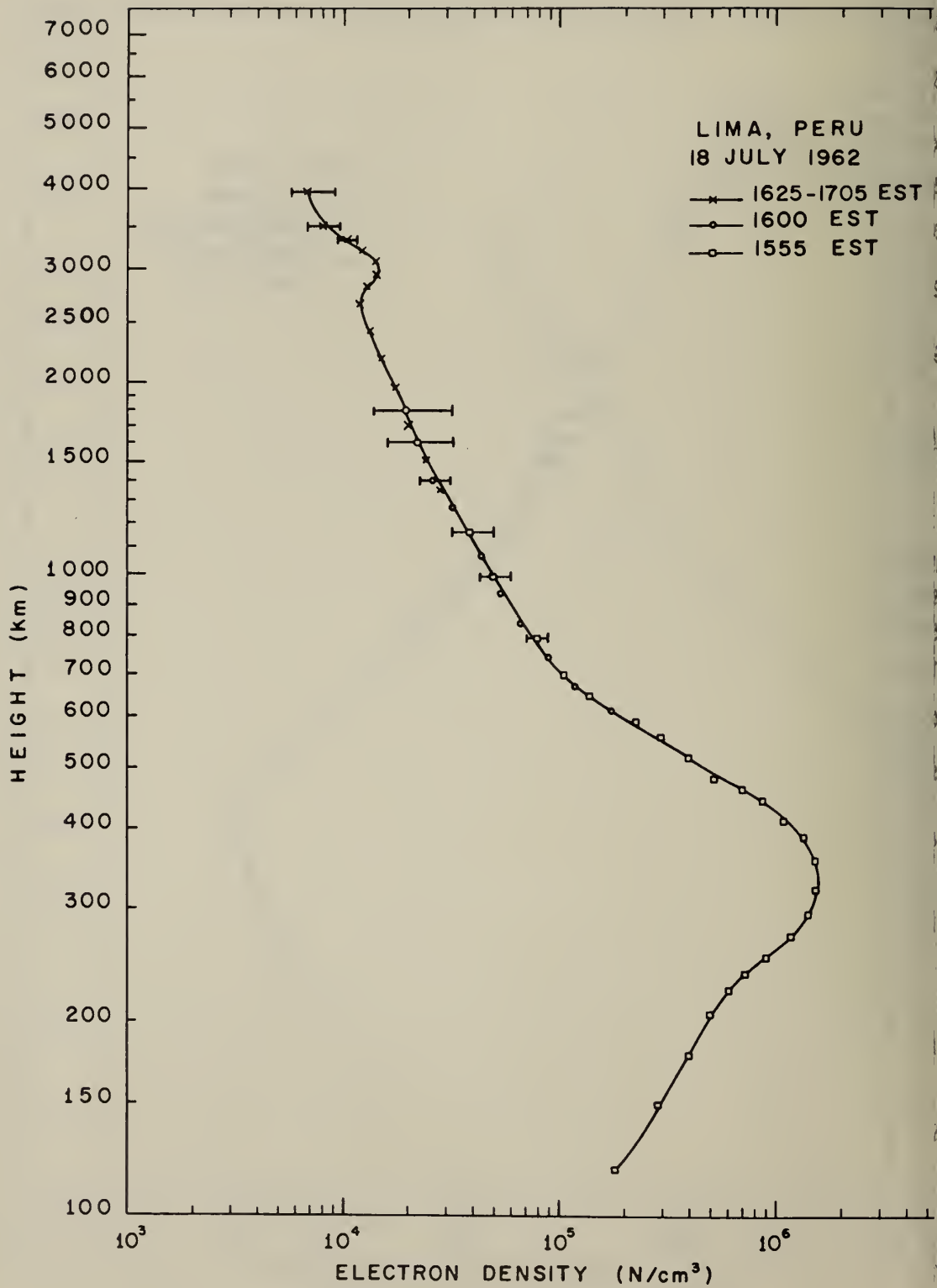
Bowles, K. L., G. R. Ochs, and J. L. Green, On the absolute intensity of incoherent scatter echoes from the ionosphere, J. Res. NBS 66D (Radio Prop.), 395-407 (1962).

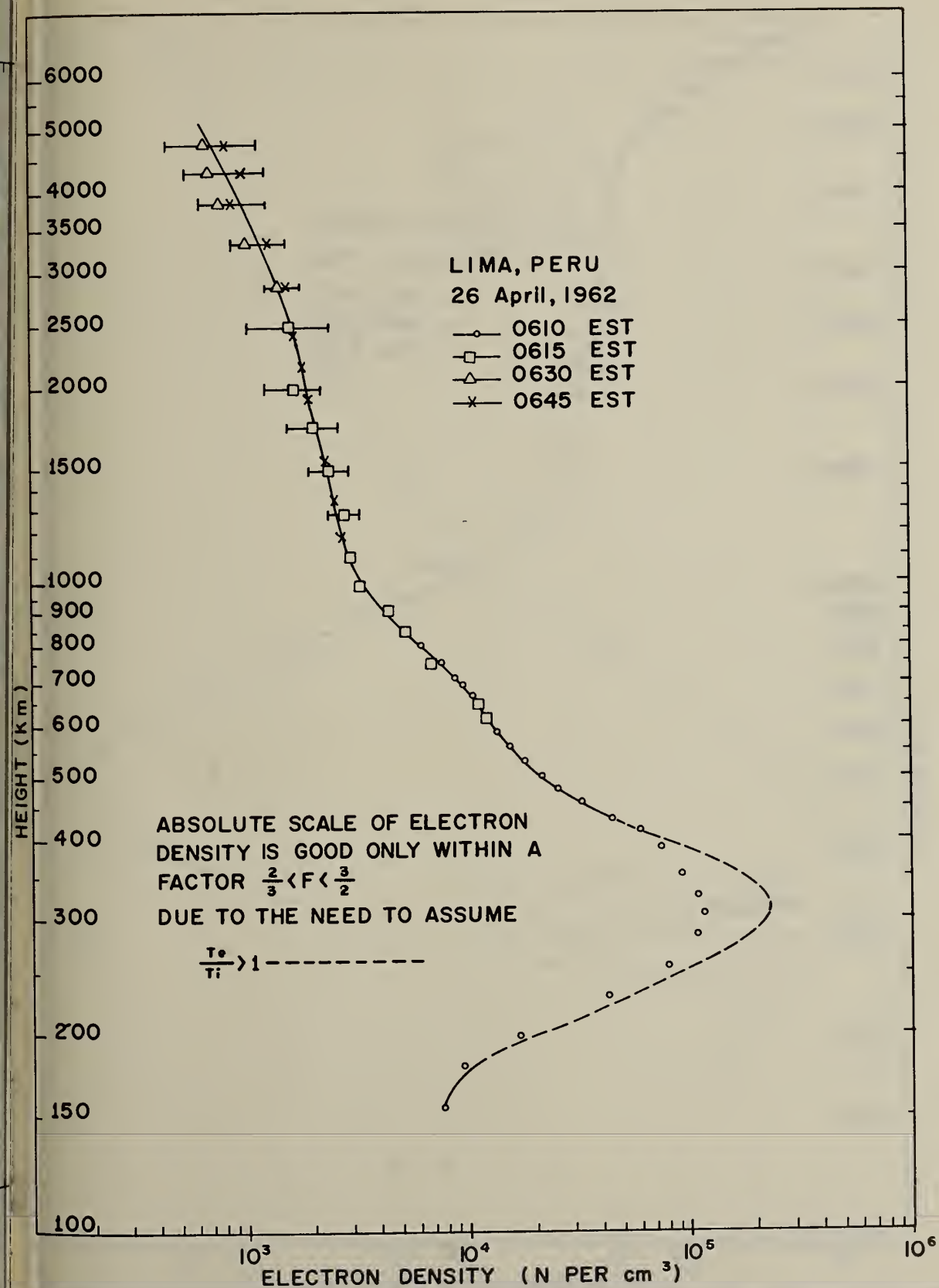
Renau, J., The cross section for scattering of electromagnetic waves from an ionized gas in thermal nonequilibrium, J. Geophys. Res. 67, 3624-3526 (Aug. 1962).

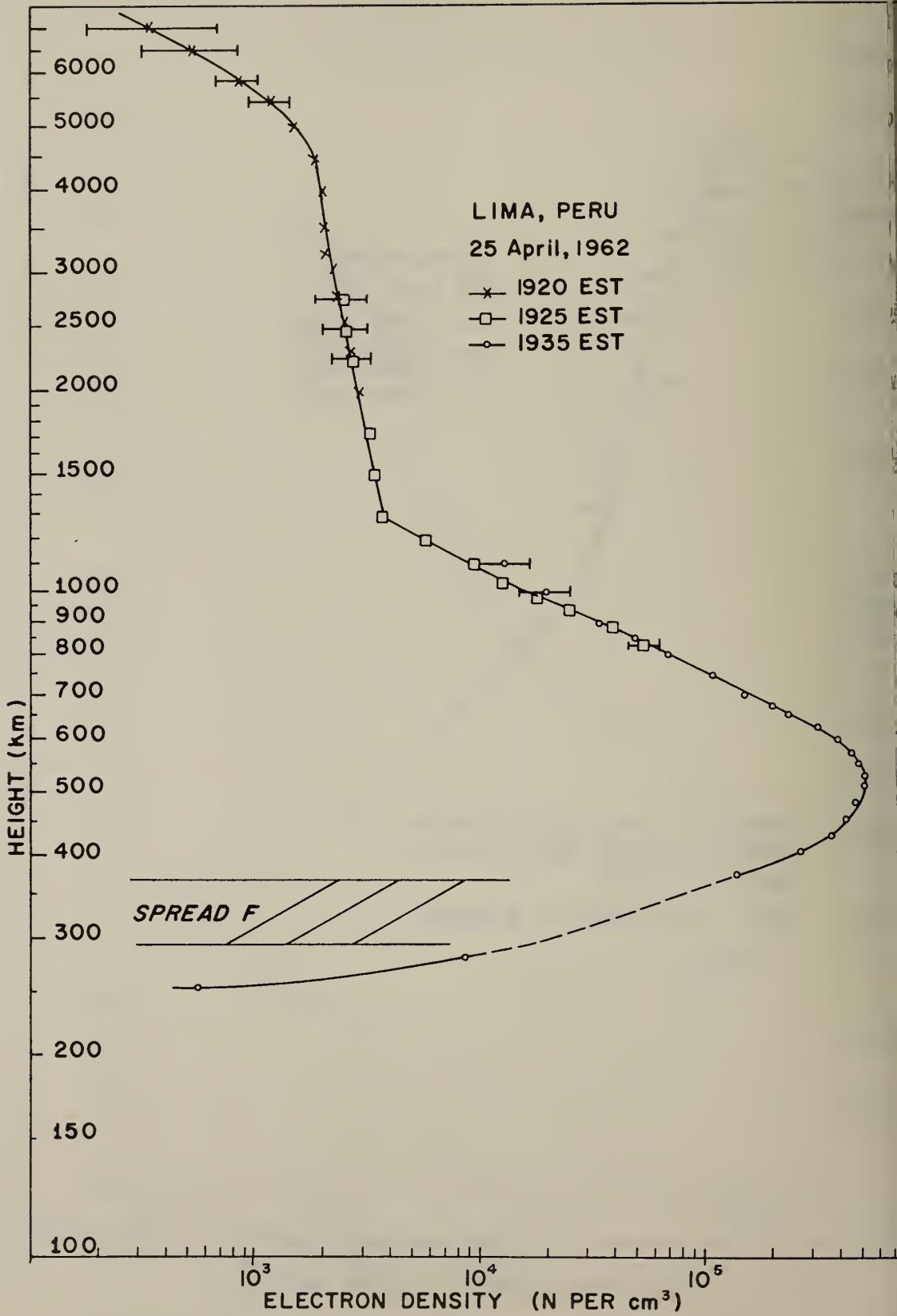


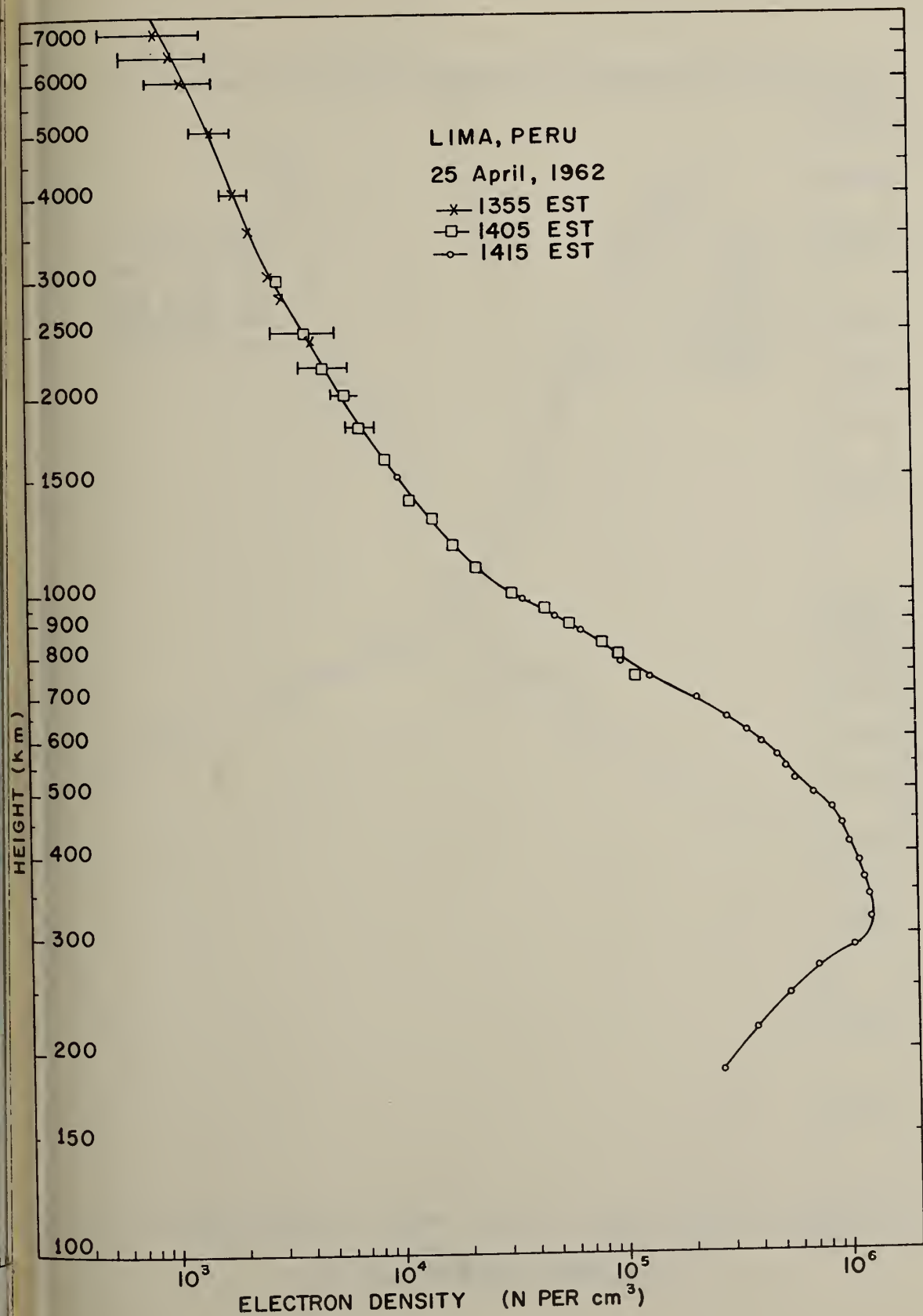


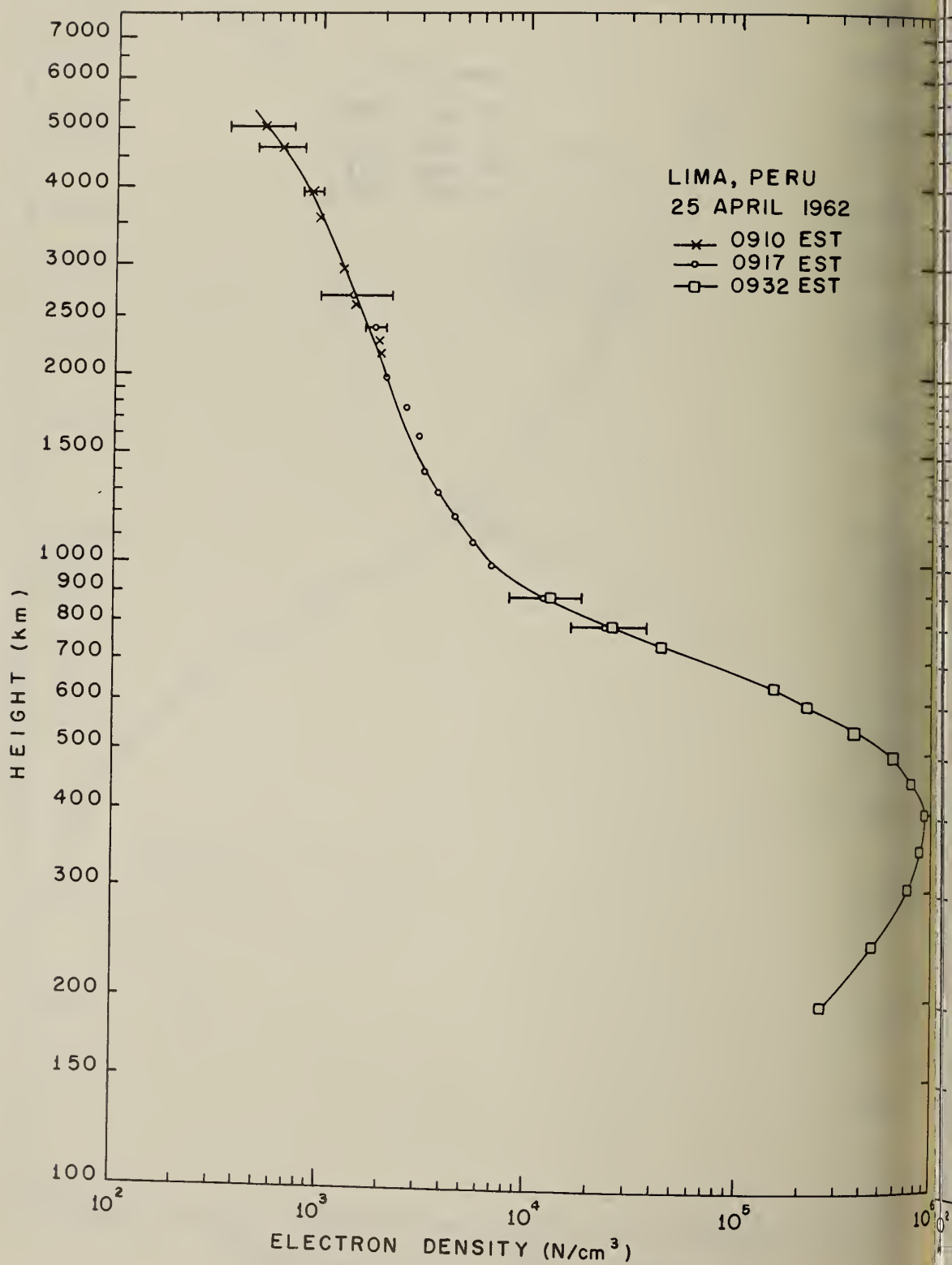


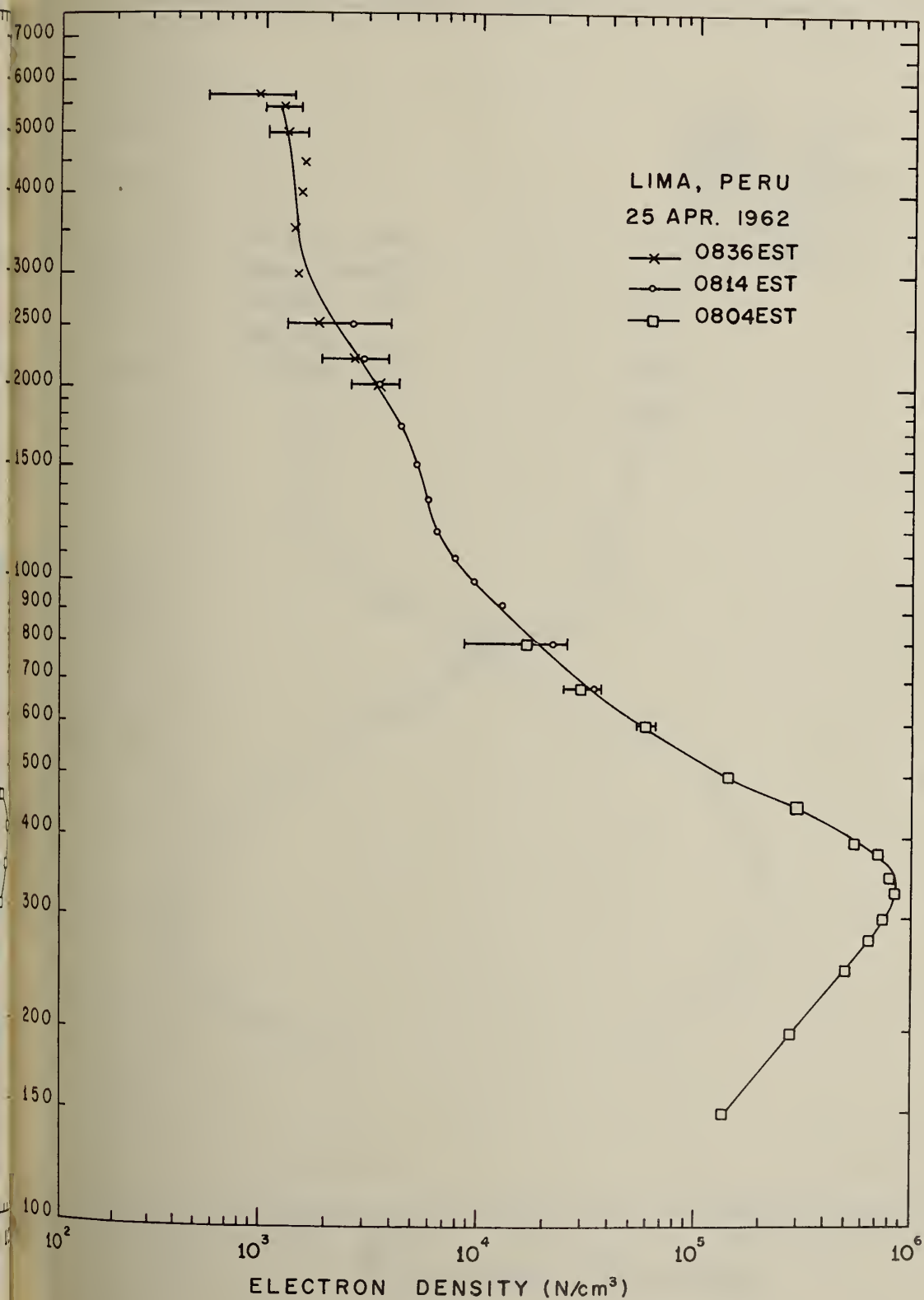


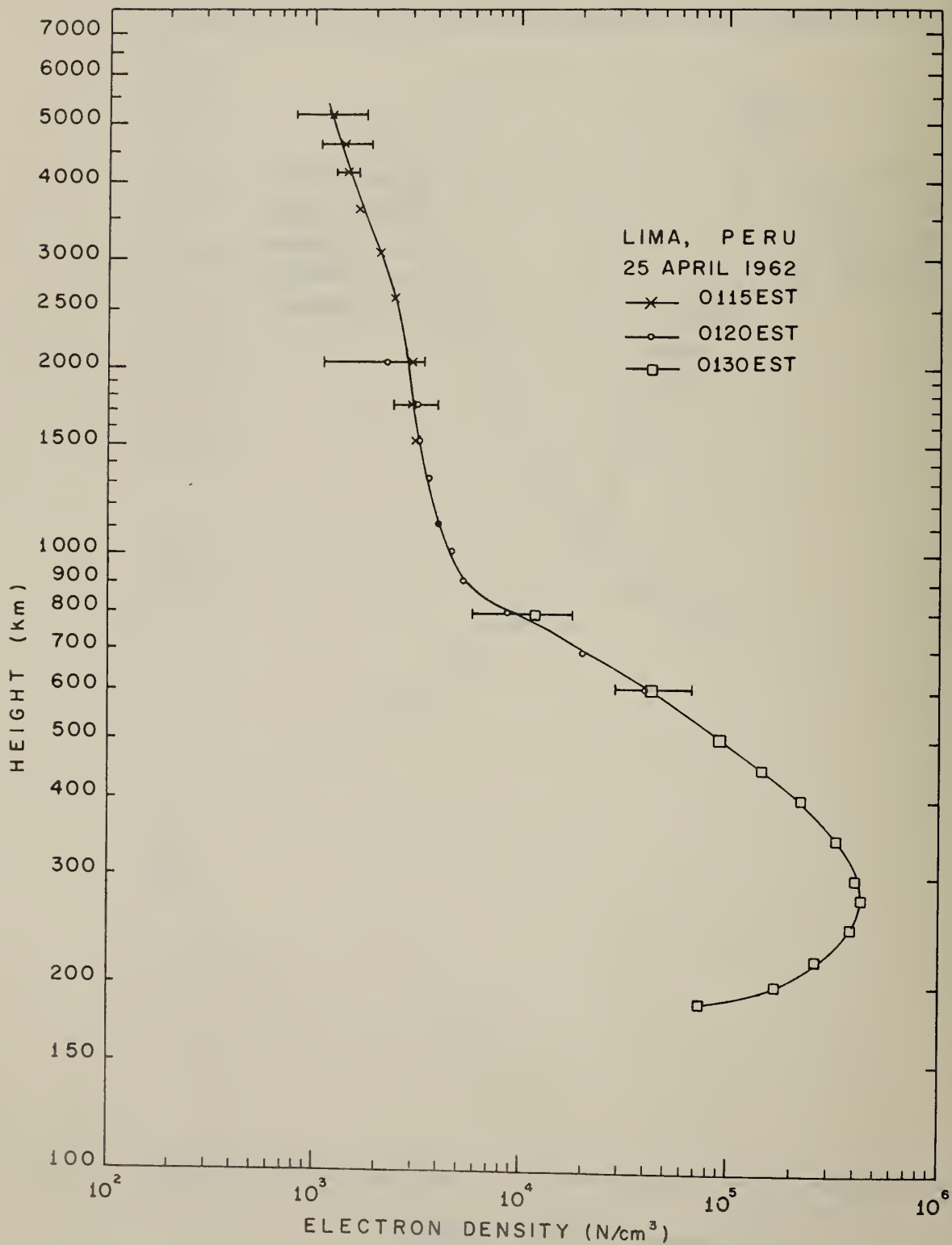


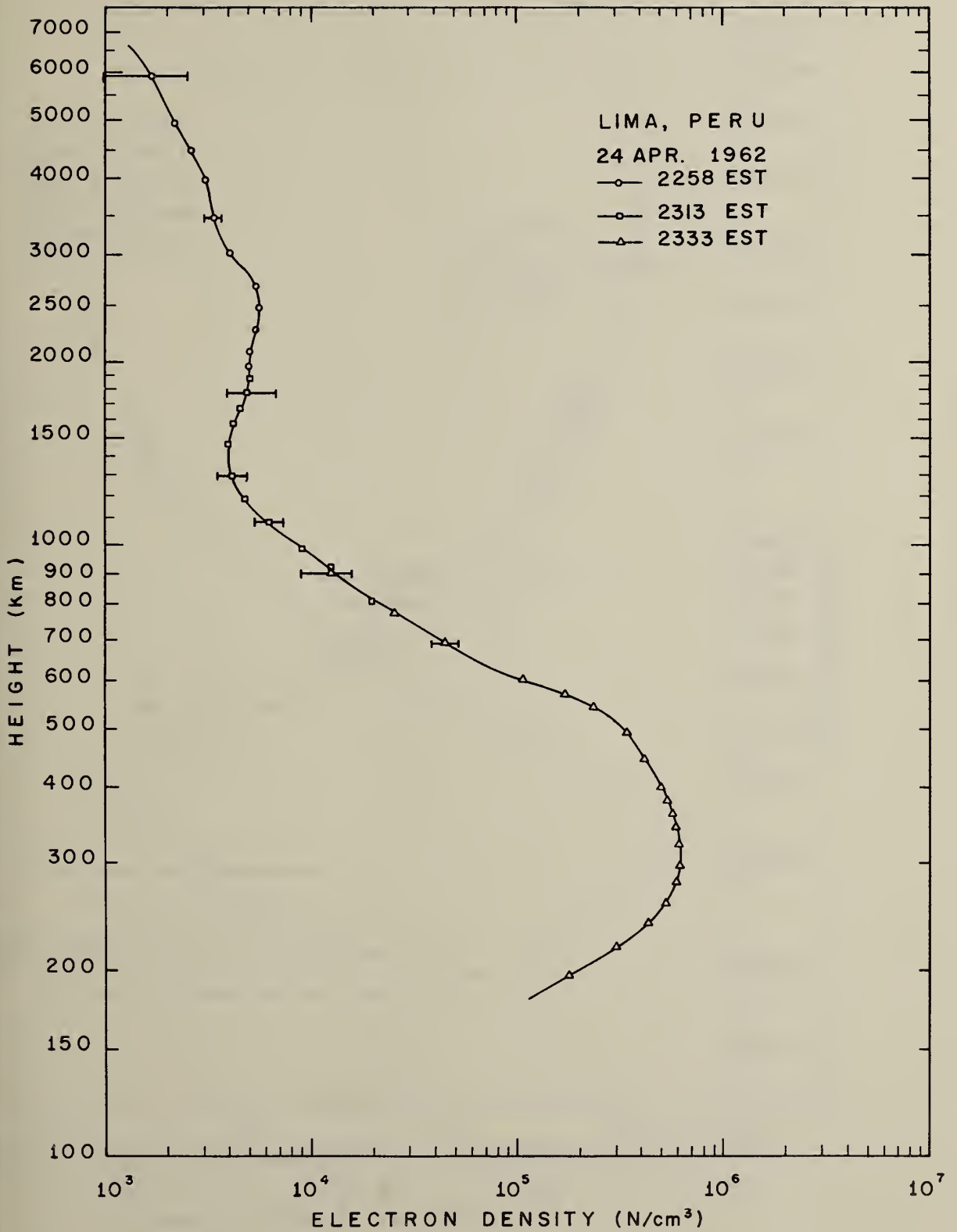


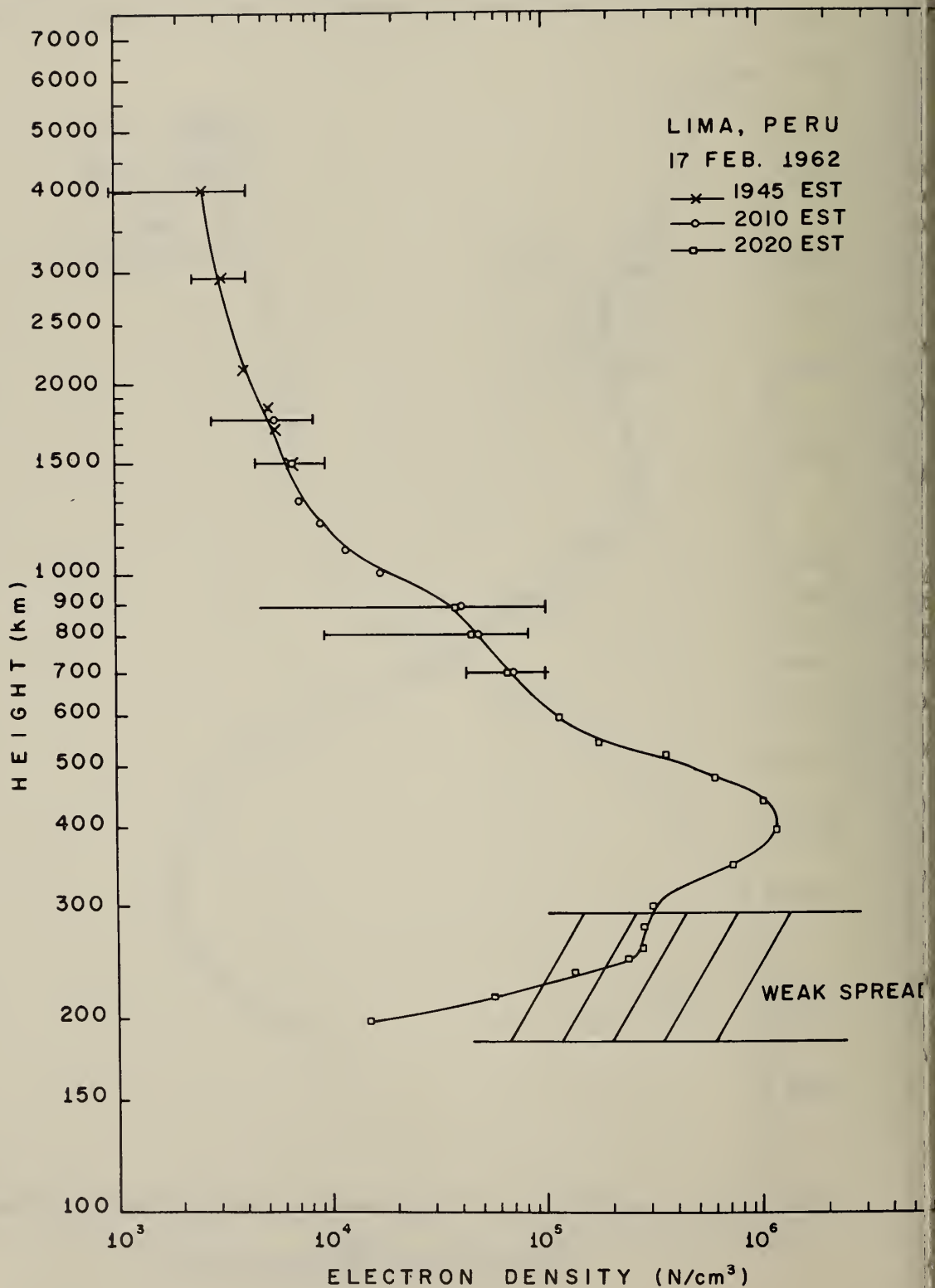


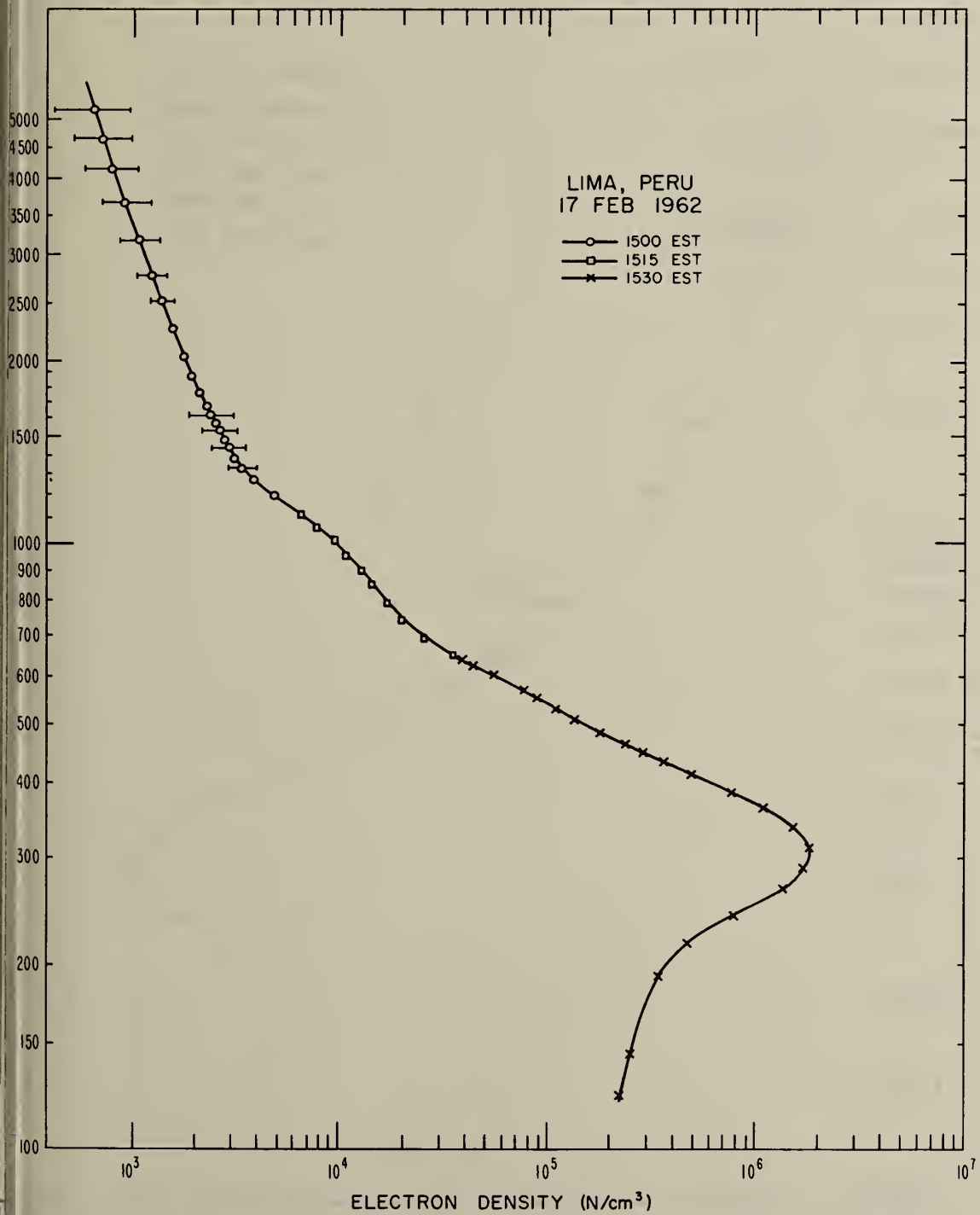


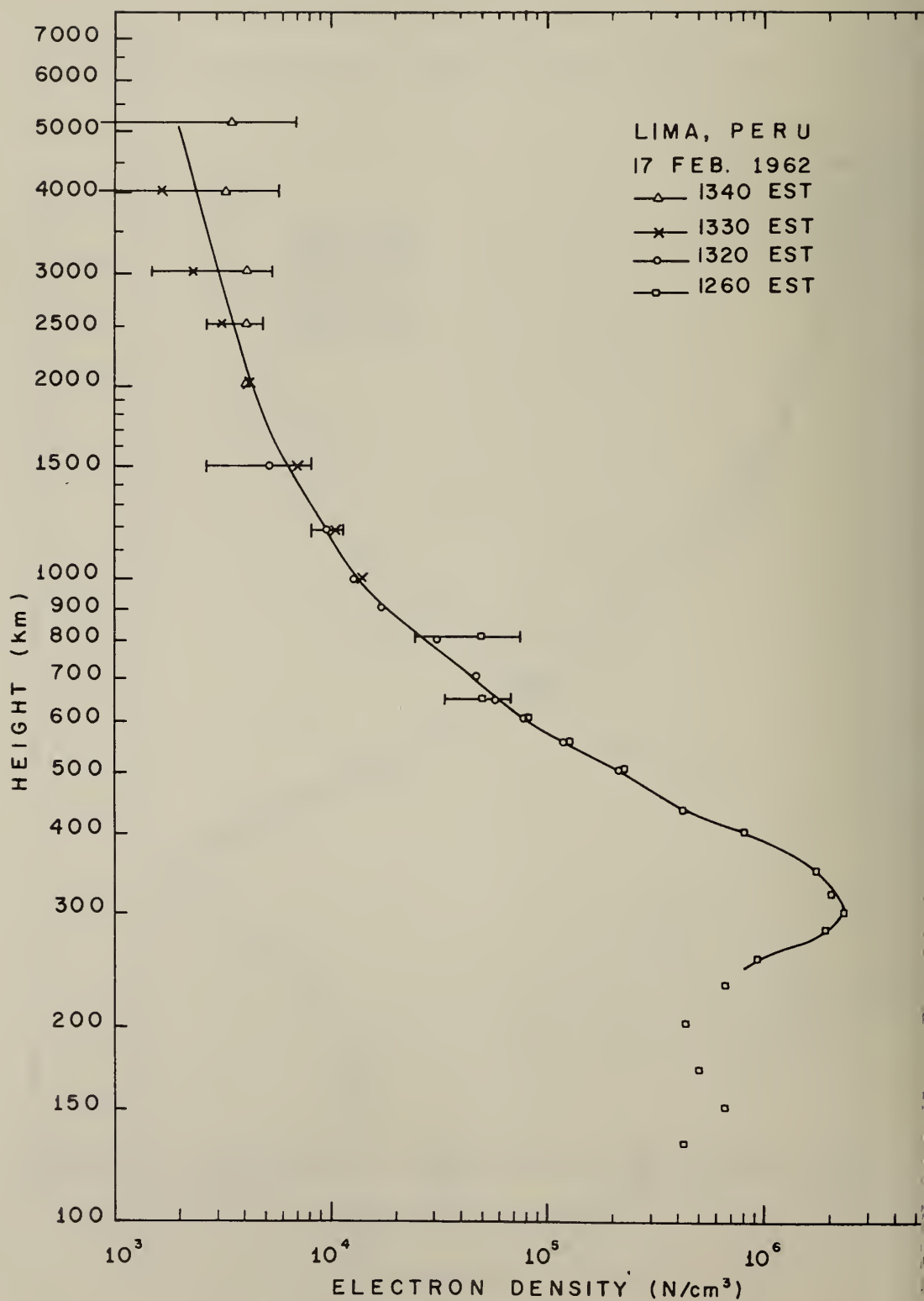


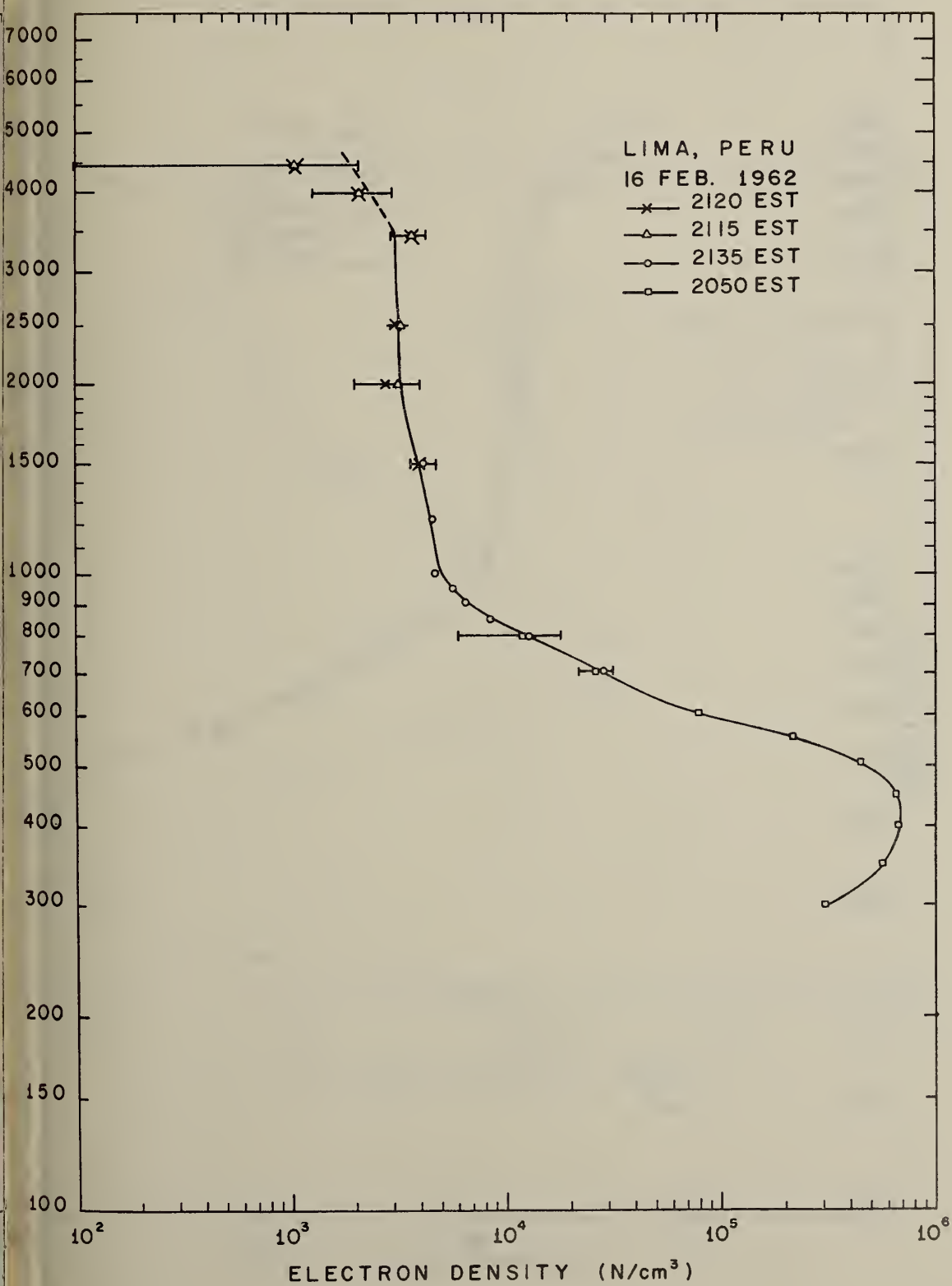


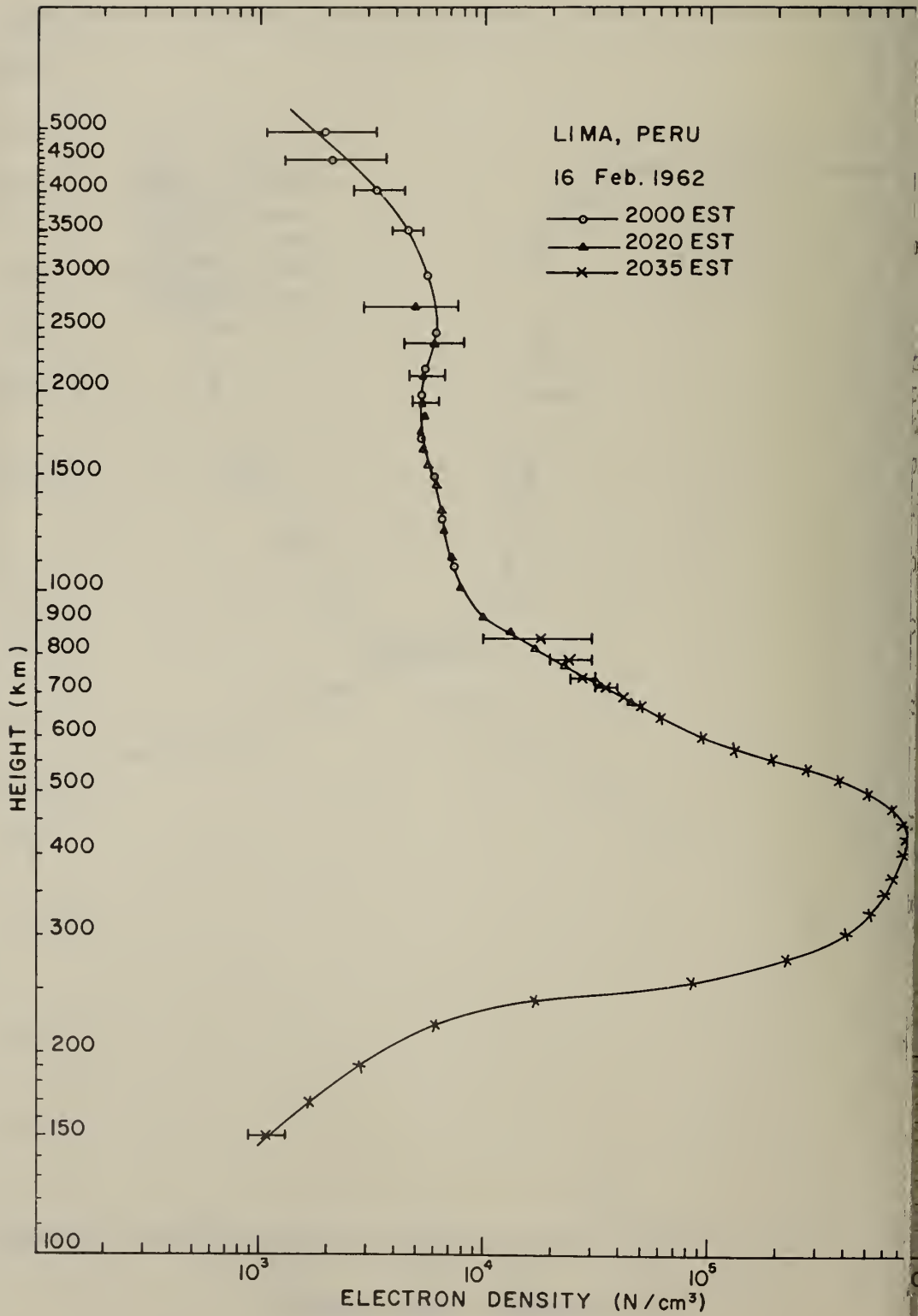


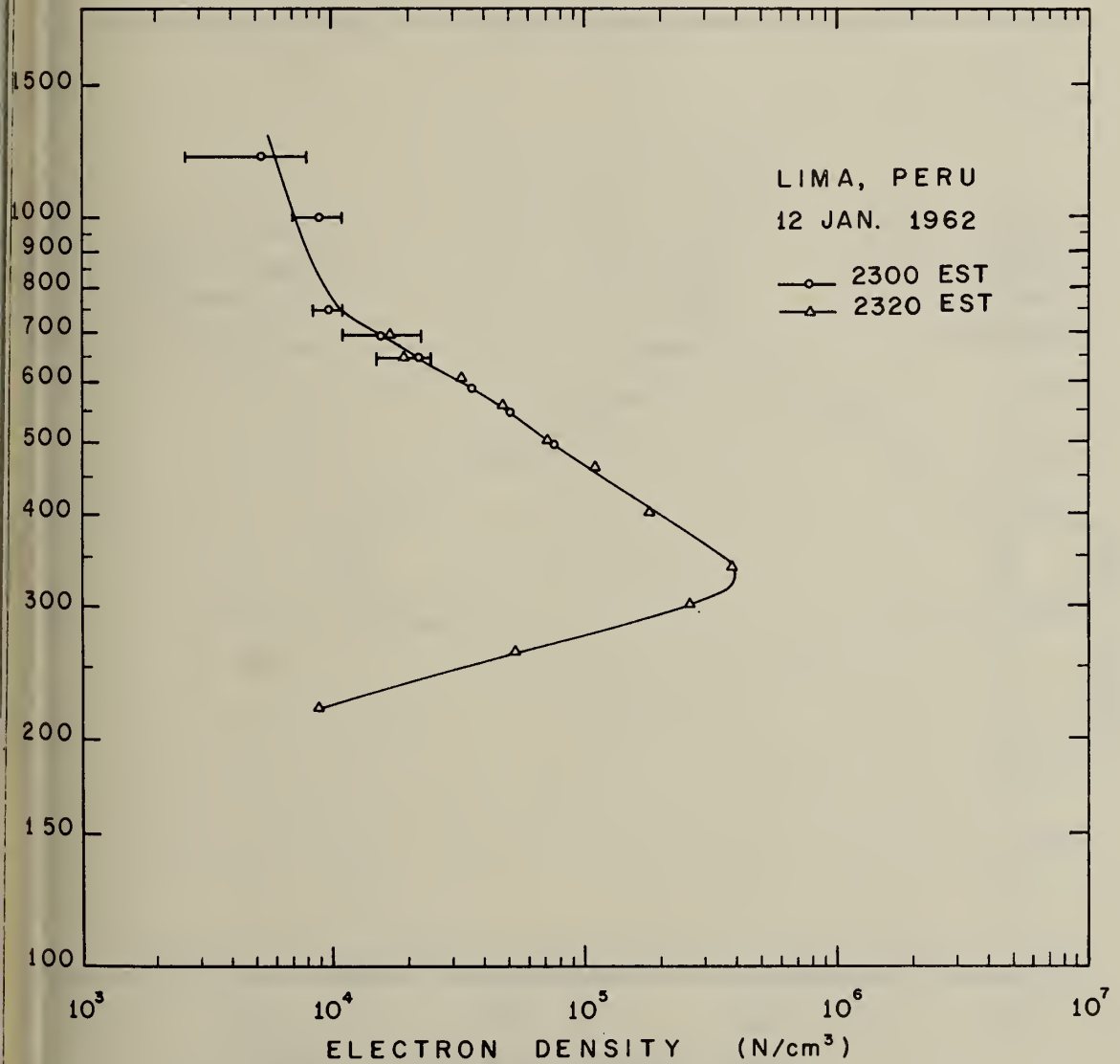


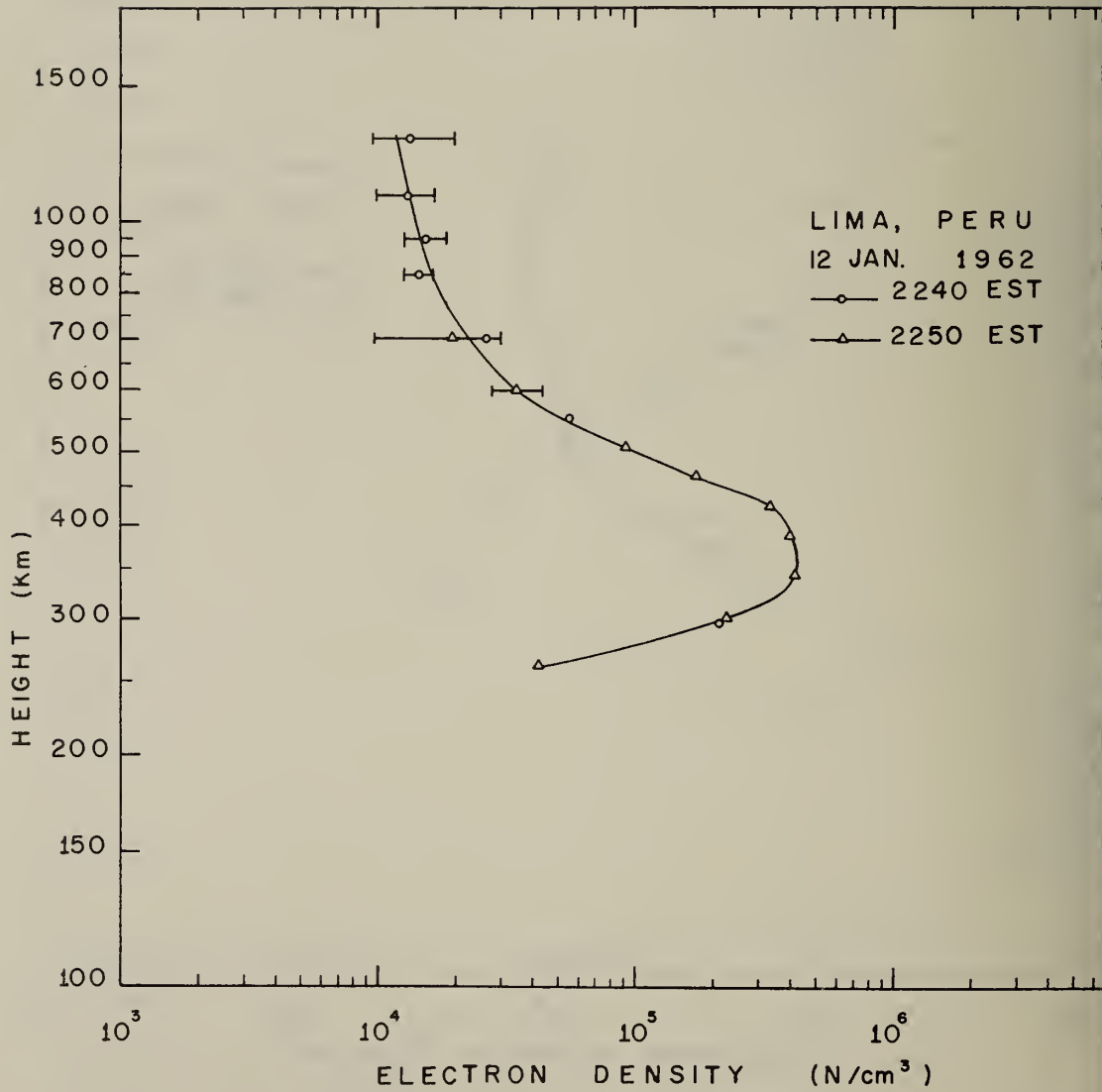


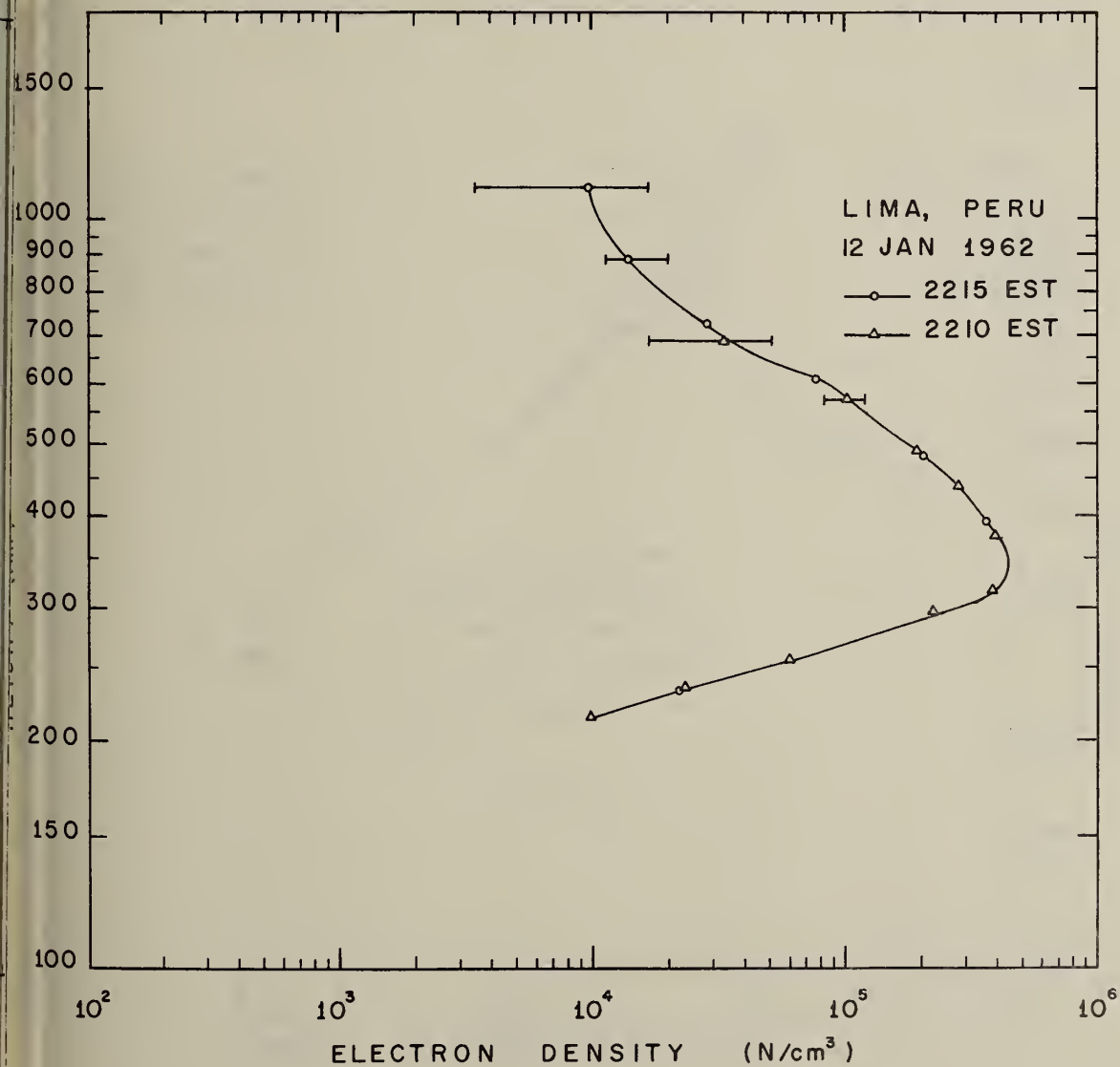


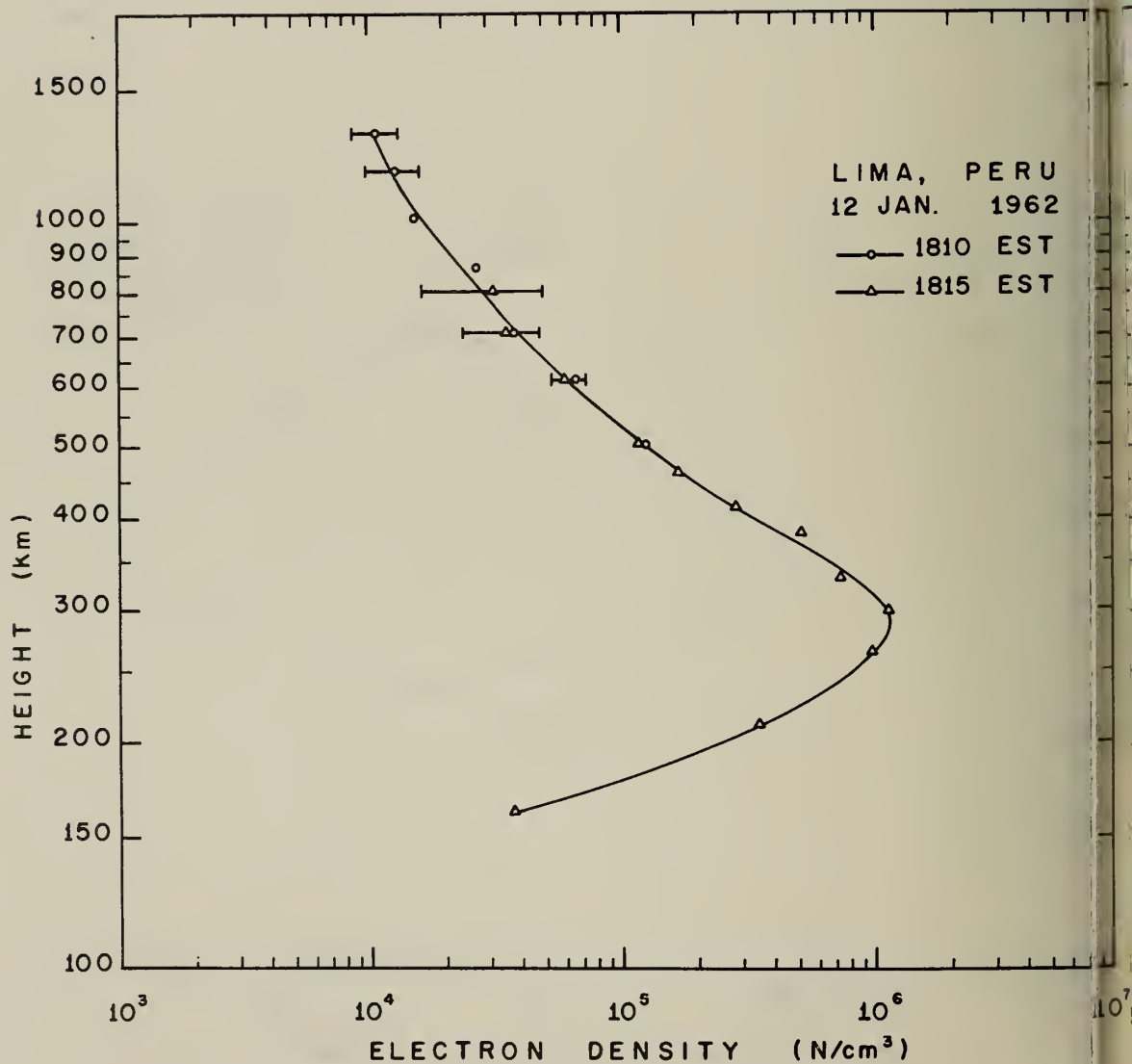


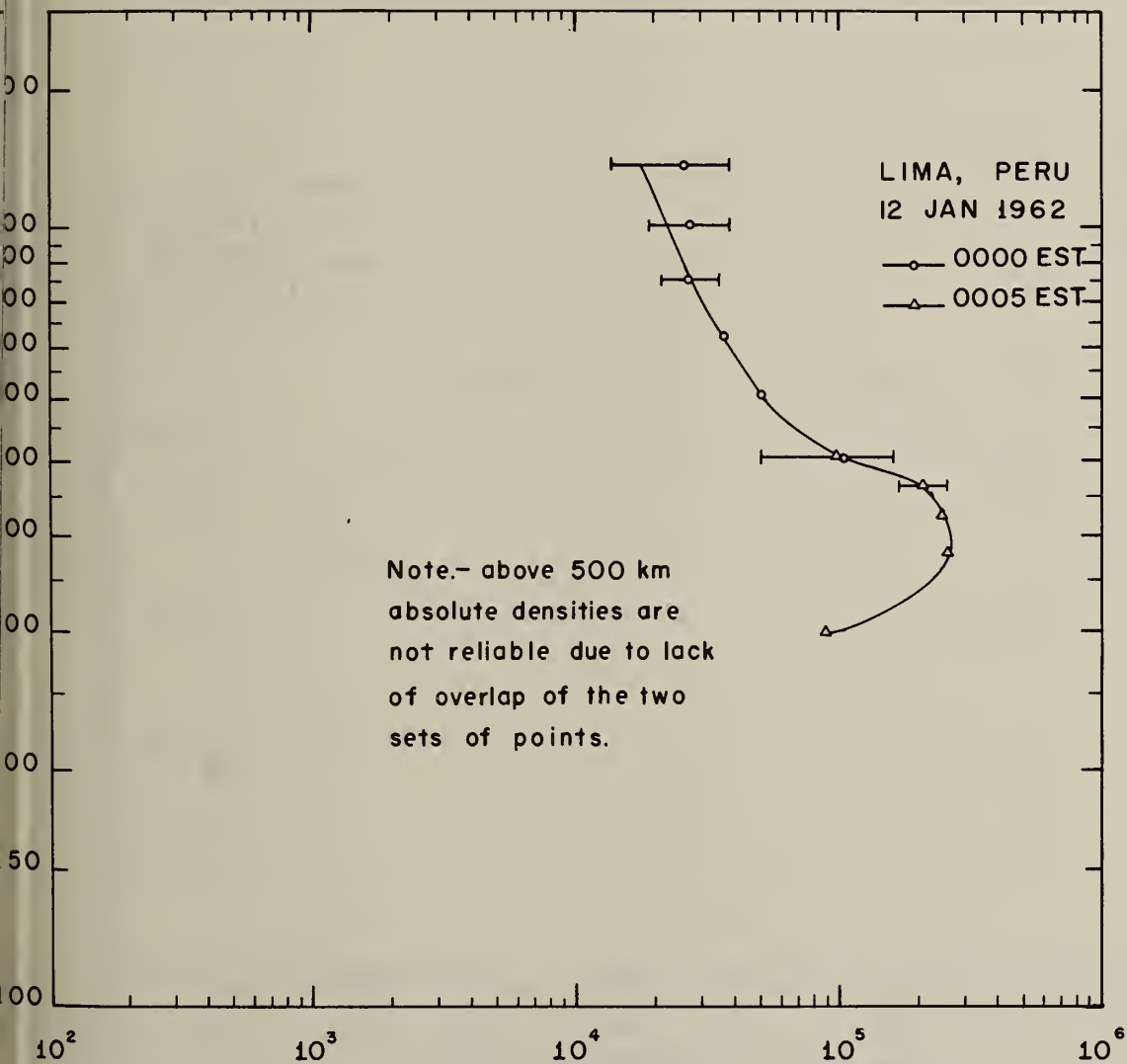


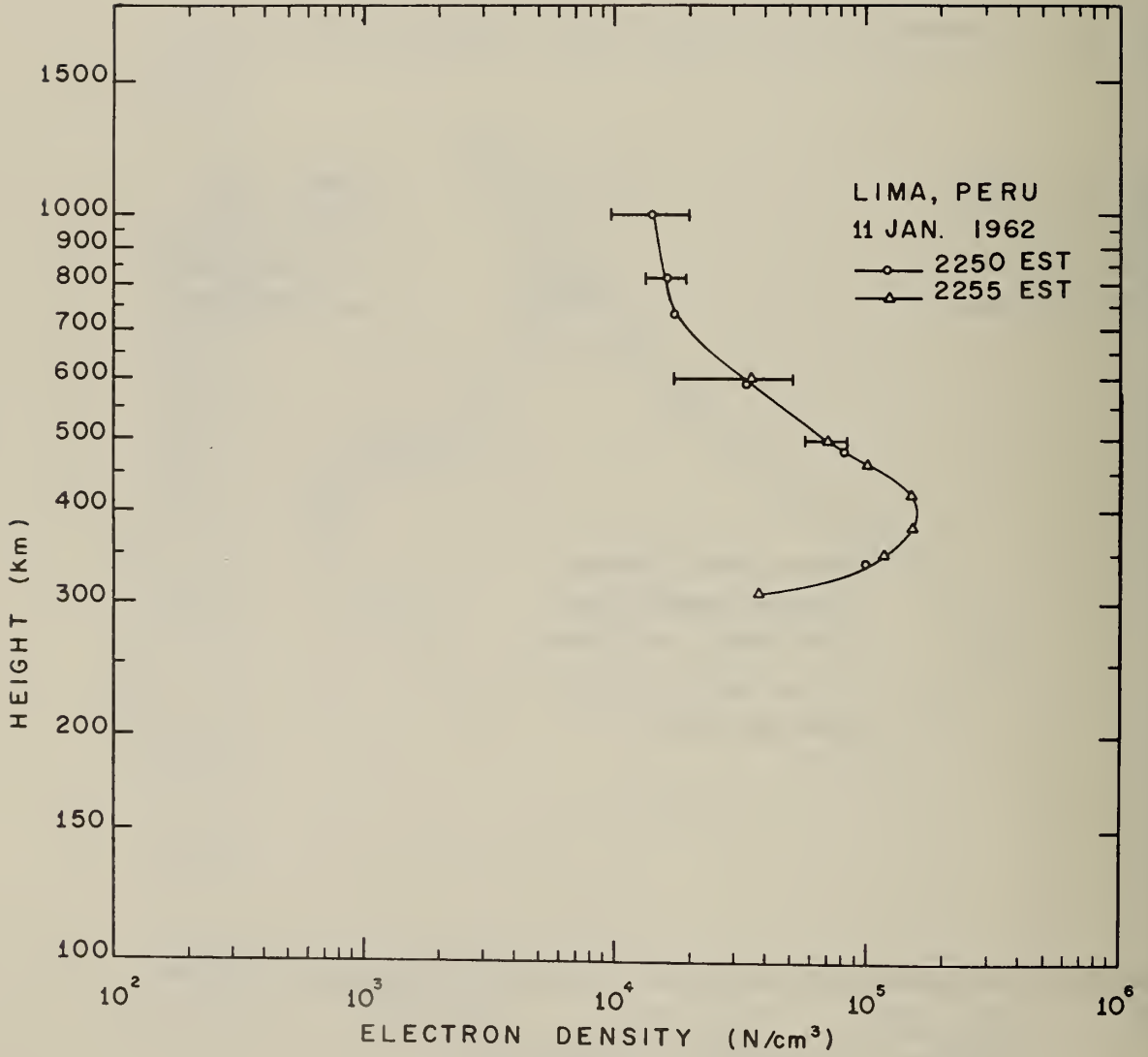


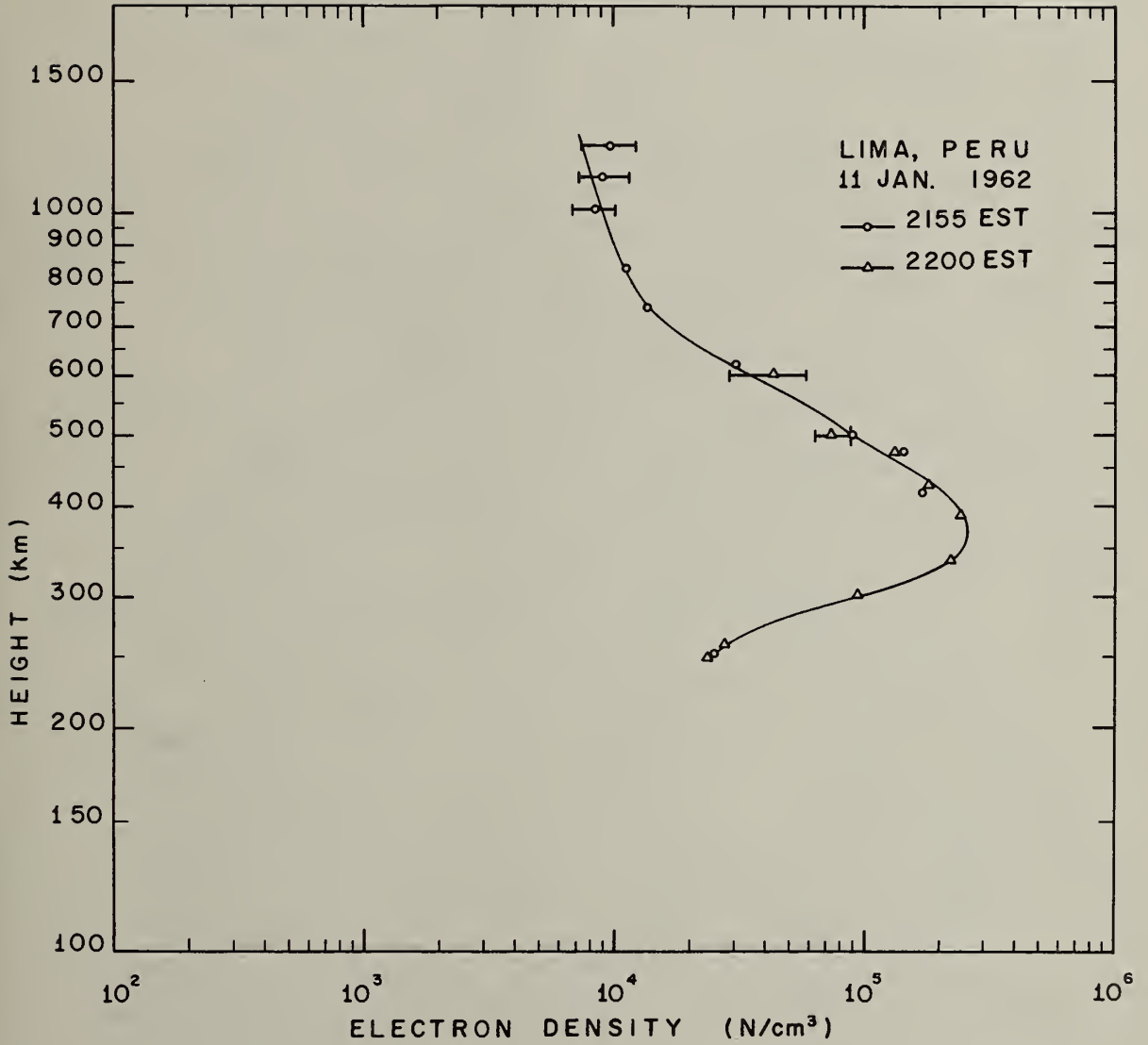


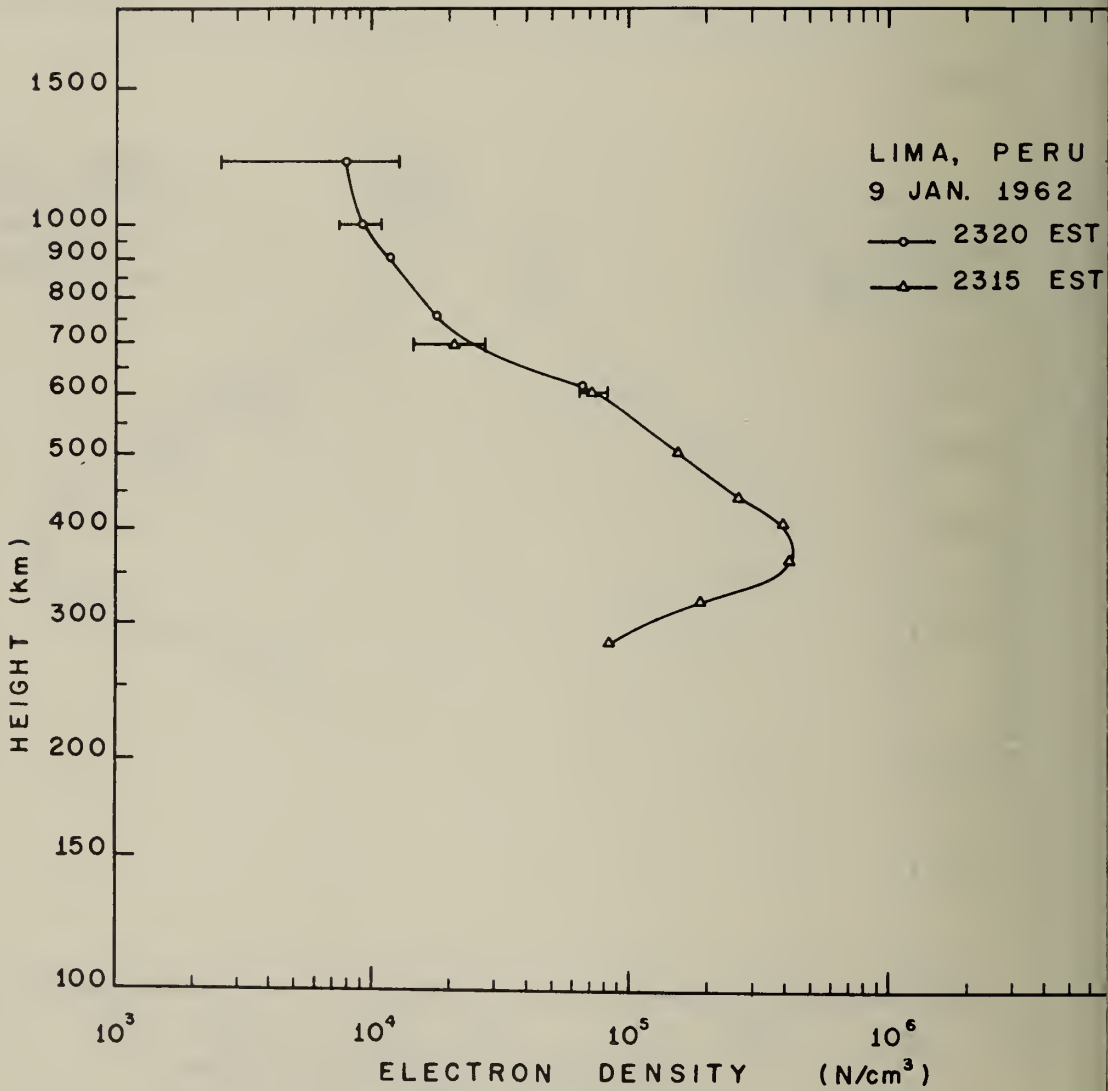














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